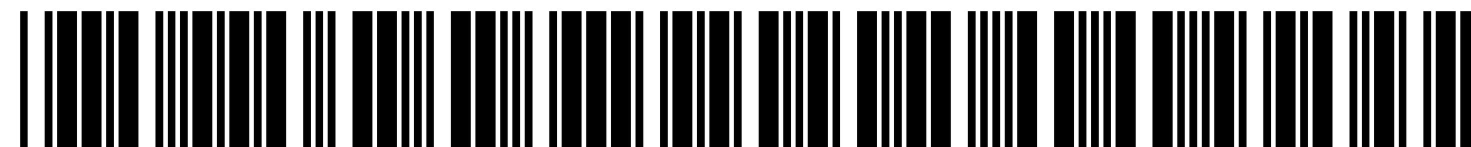

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Park et al.

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(45) **Date of Patent: Dec. 21, 2010**

(54) **BIPOLAR JUNCTION TRANSISTOR-BASED UNCOOLED INFRARED SENSOR AND MANUFACTURING METHOD THEREOF**

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(73) Assignee: **Electronics and Telecommunications Research Institute**, Daejeon (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 290 days.

(21) Appl. No.: **12/111,830**

(22) Filed: **Apr. 29, 2008**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
G01J 5/20 (2006.01)

(52) **U.S. Cl.** **250/338.4**

(58) **Field of Classification Search** 250/338.1, 250/338.3, 338.4; 438/54, 57
See application file for complete search history.

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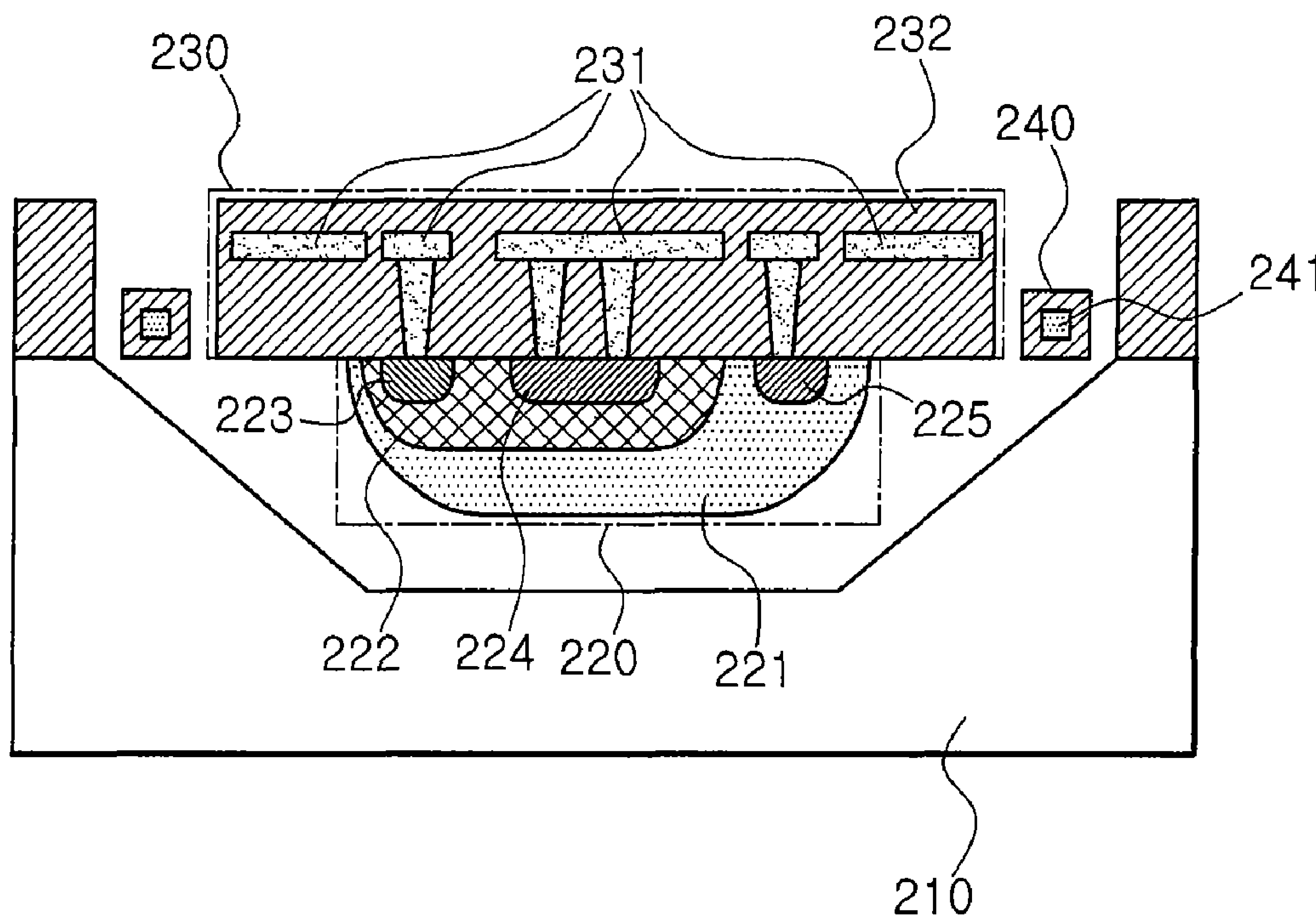
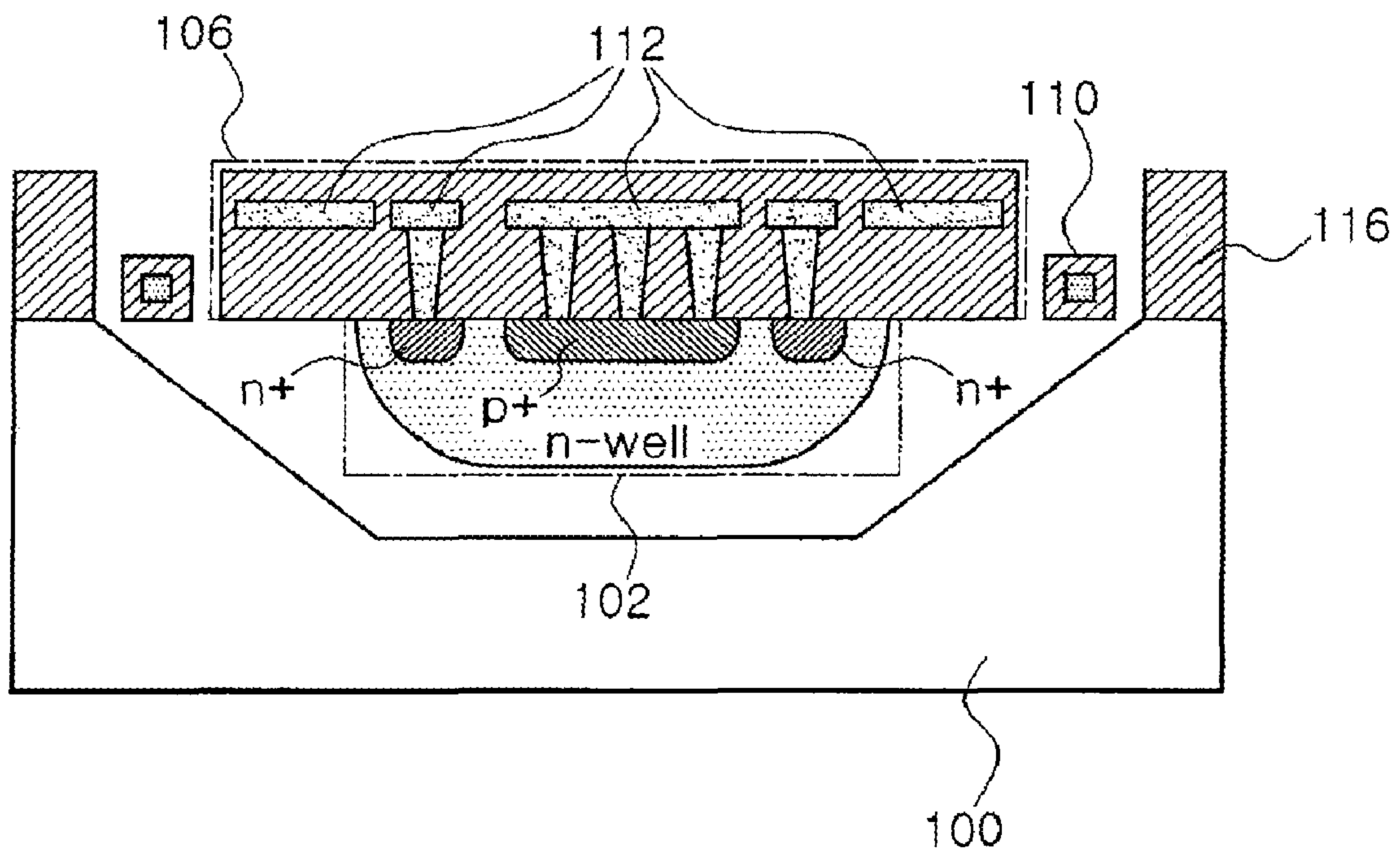
Primary Examiner—David P Porta
Assistant Examiner—Mark R Gaworecki

(57) **ABSTRACT**

A BJT (bipolar junction transistor)-based uncooled IR sensor and a manufacturing method thereof are provided. The BJT-based uncooled IR sensor includes: a substrate; at least one BJT which is formed to be floated apart from the substrate; and a heat absorption layer which is formed on an upper surface of the at least one BJT, wherein the BJT changes an output value according heat absorbed through the heat absorption layer. Accordingly, it is possible to provide a BJT-based uncooled IR sensor capable of being implemented through a CMOS compatible process and obtaining more excellent temperature change detection characteristics.

4 Claims, 19 Drawing Sheets





PRIOR ART

FIG. 1

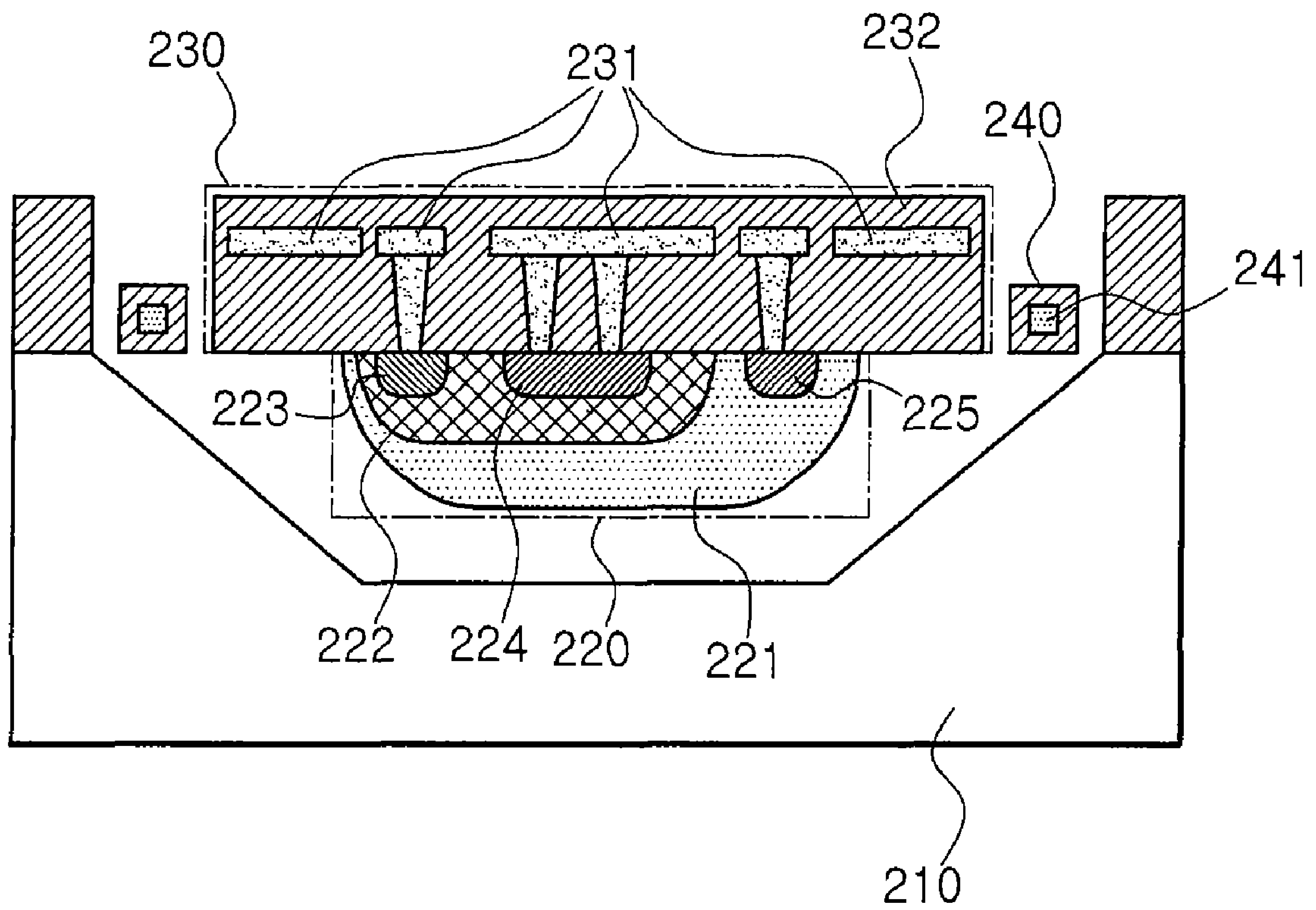


FIG. 2

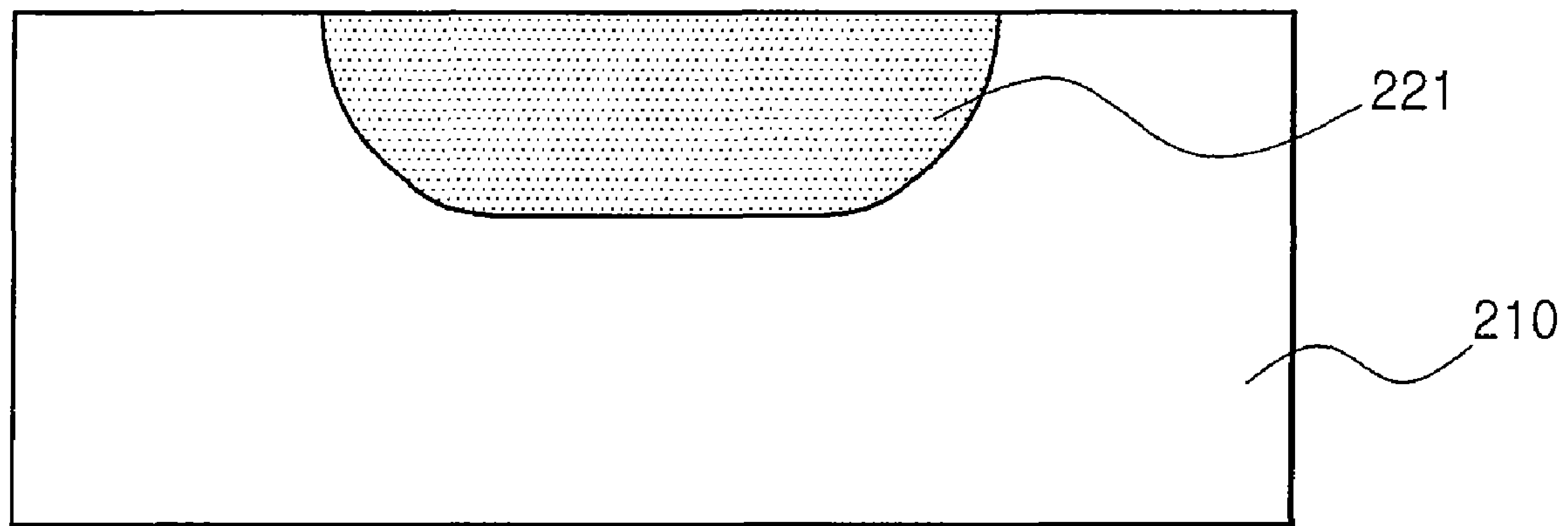


FIG. 3A

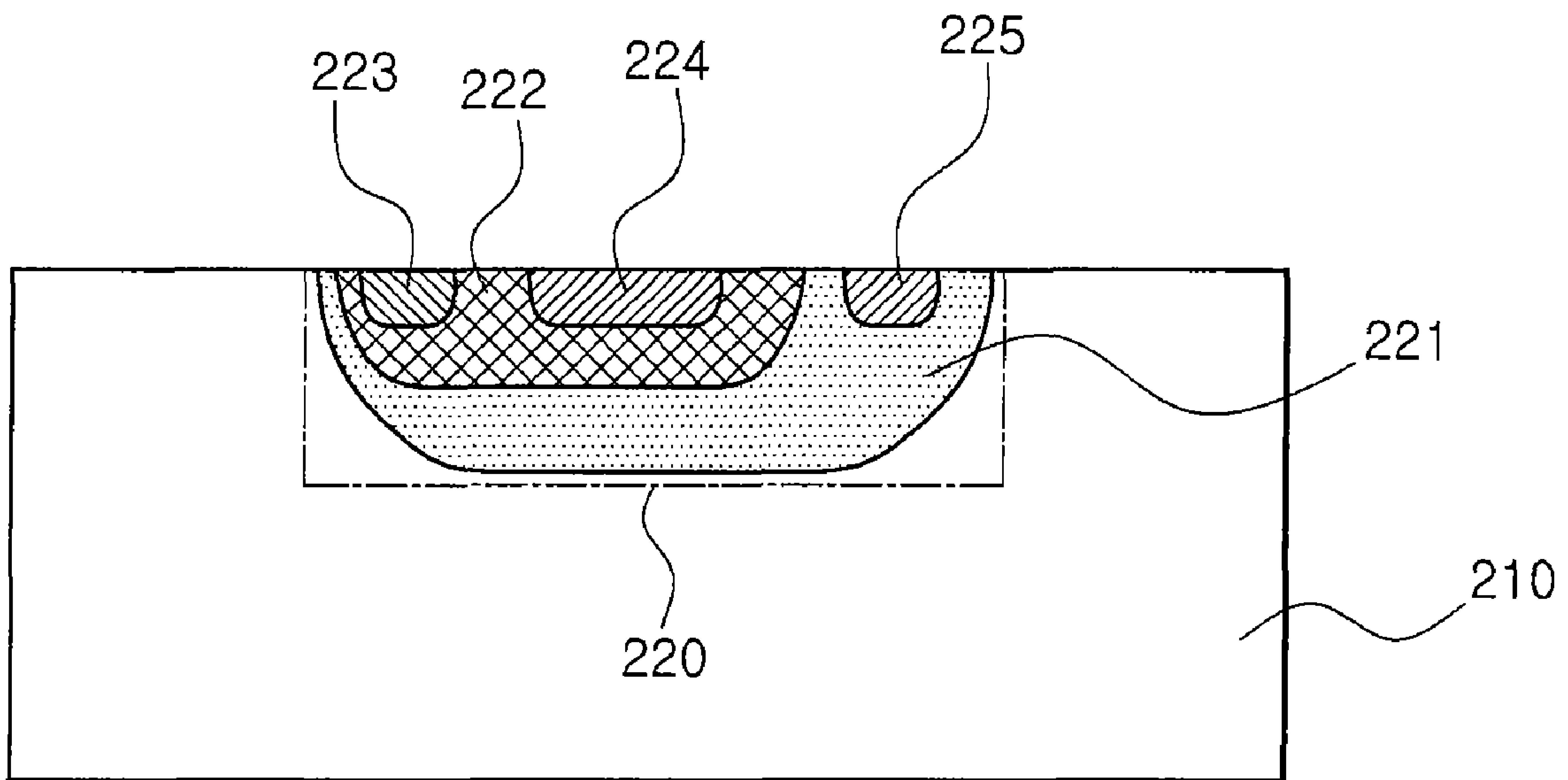


FIG. 3B

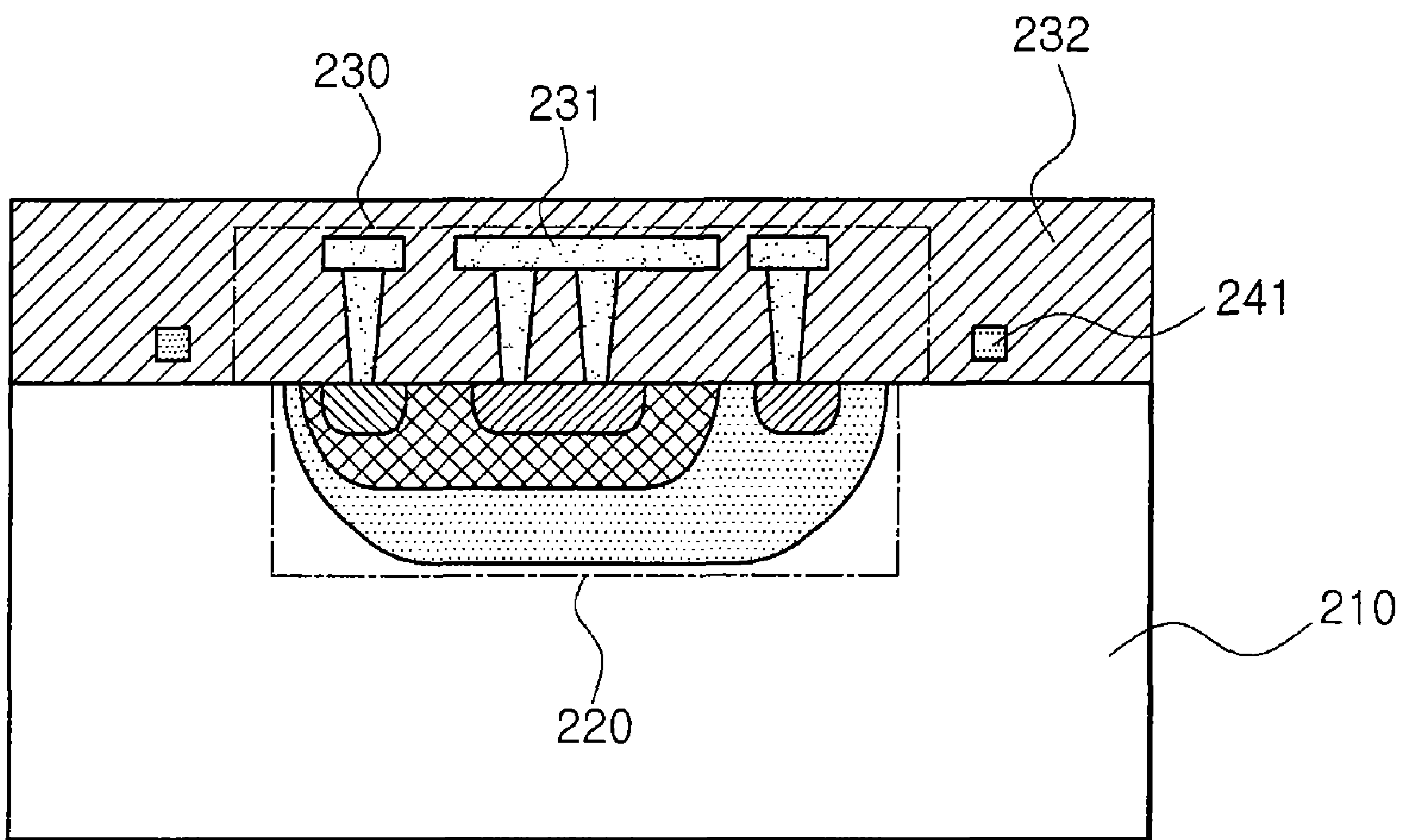


FIG. 3C

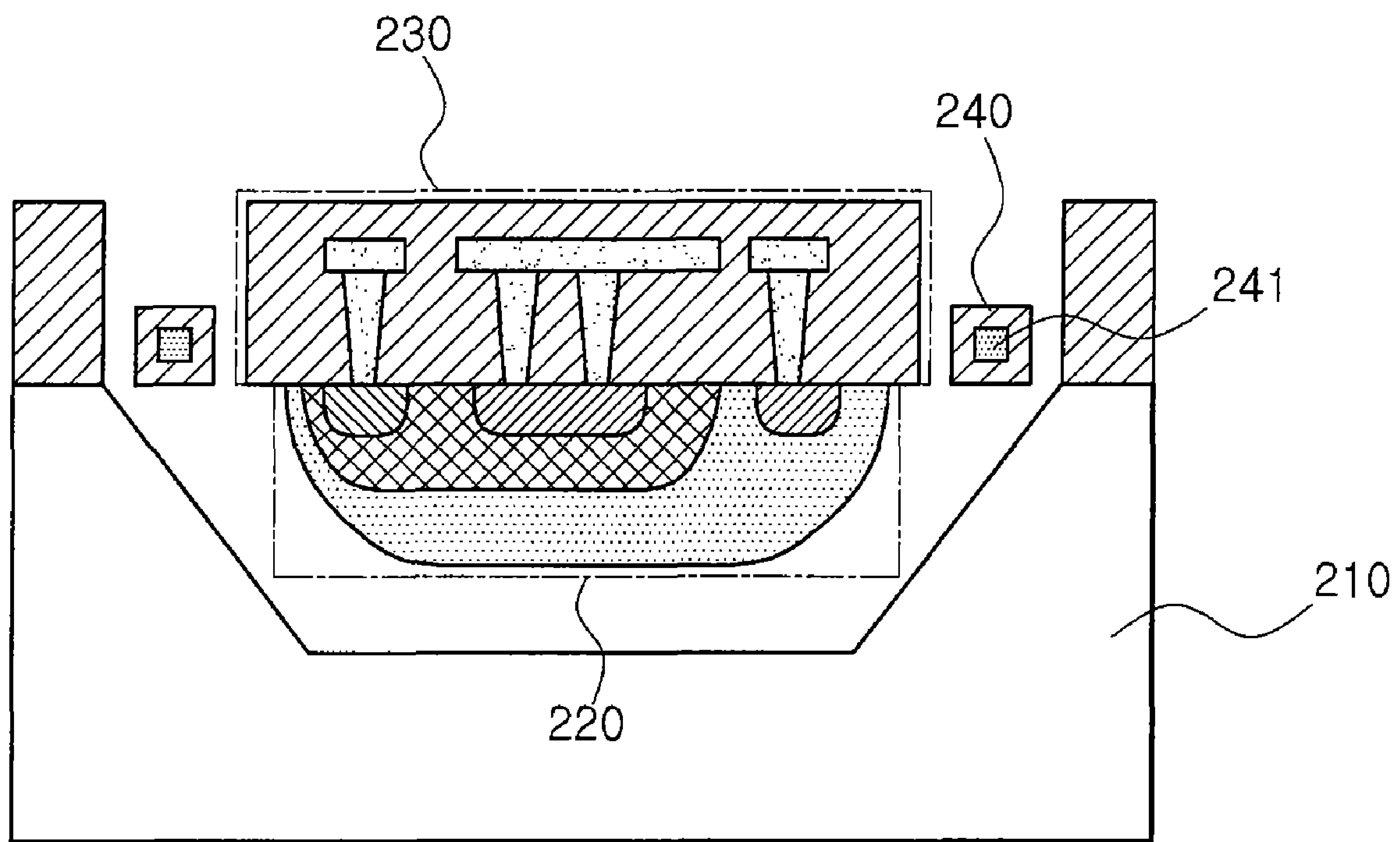


FIG. 3D

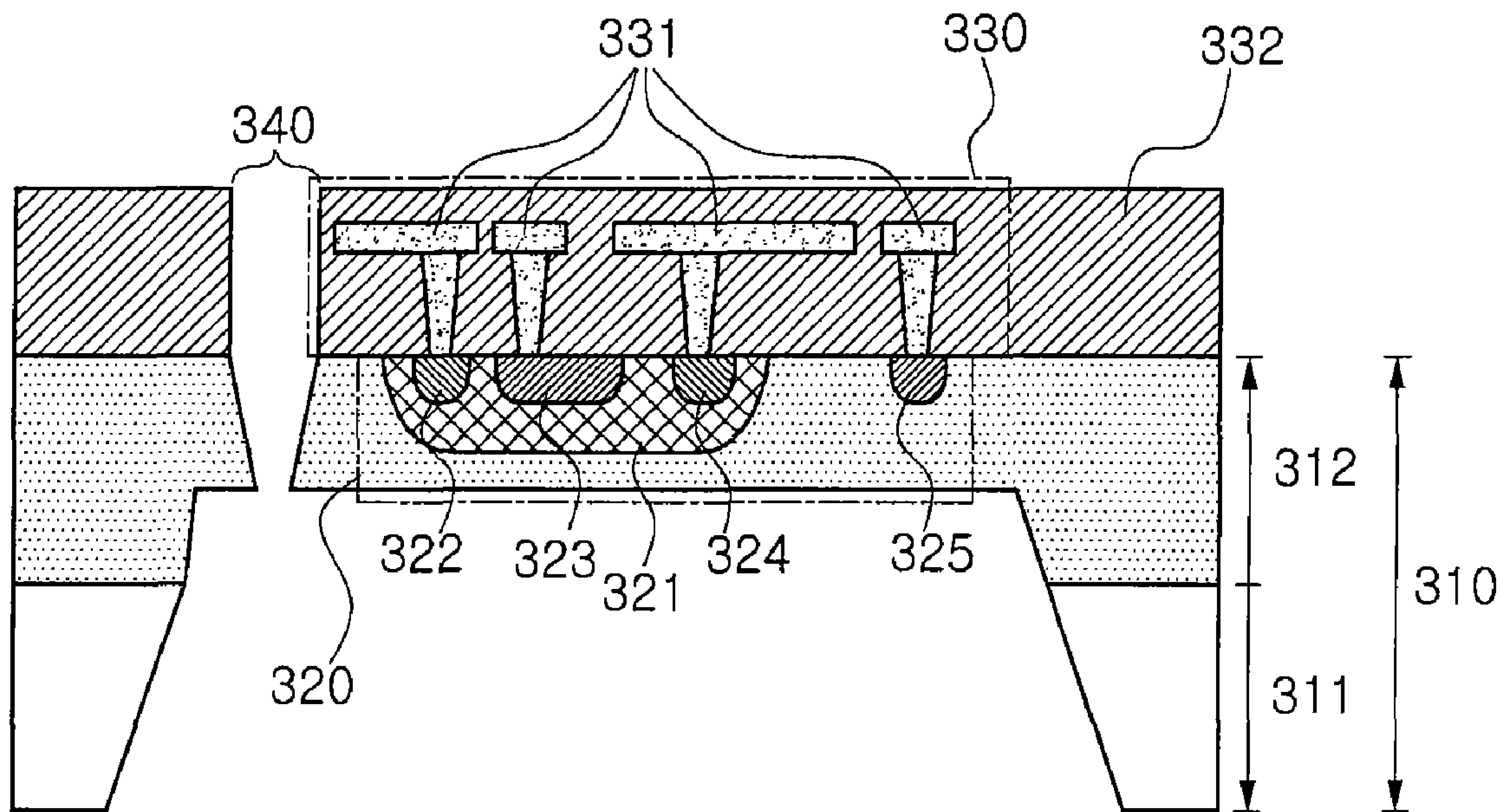


FIG.4

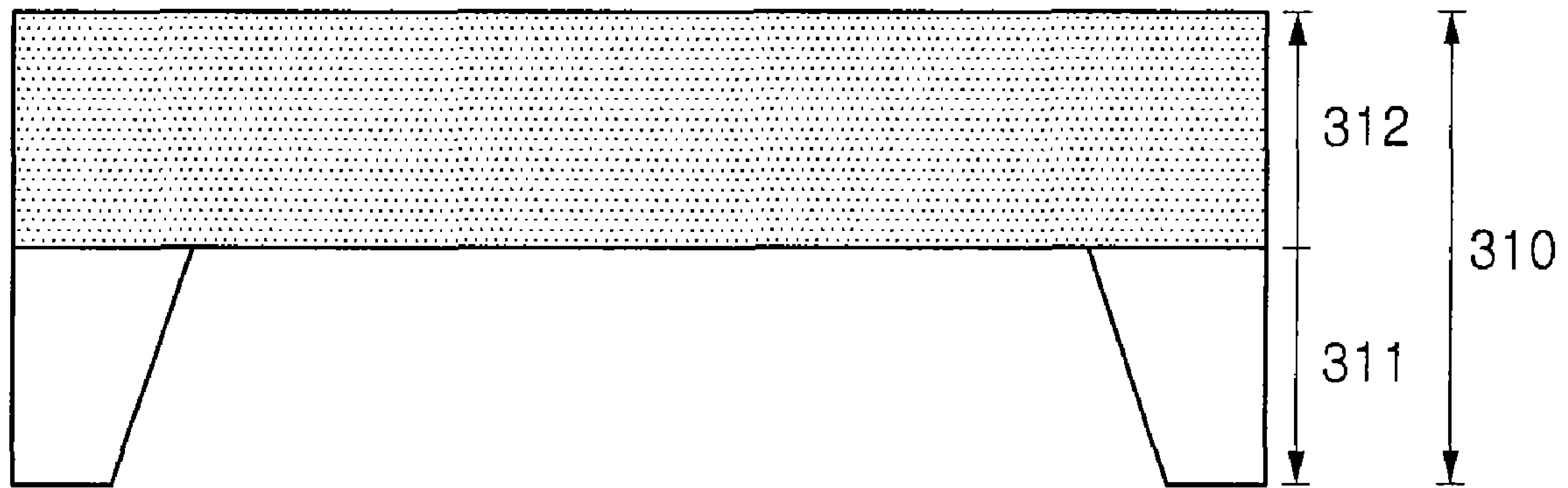


FIG. 5A

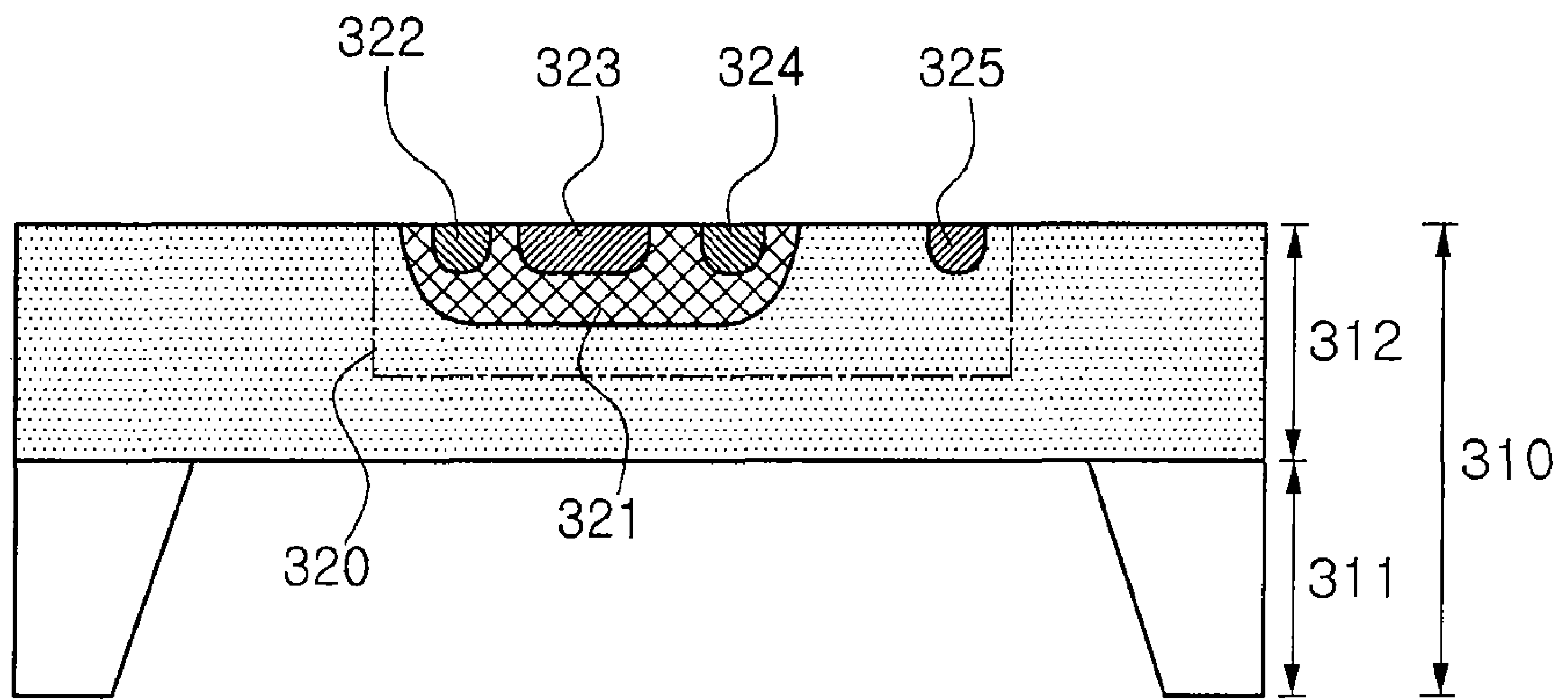


FIG. 5B

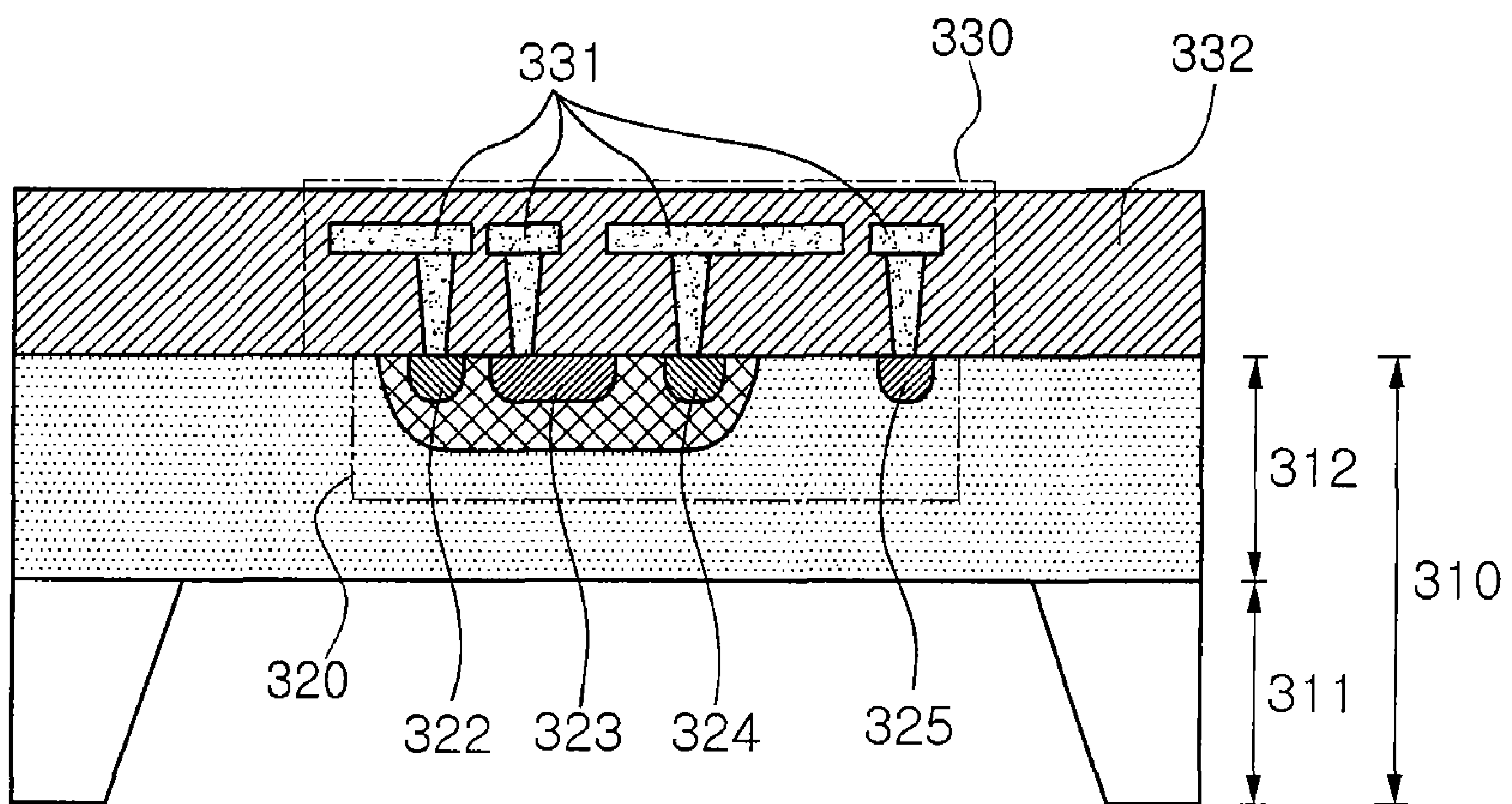


FIG. 5C

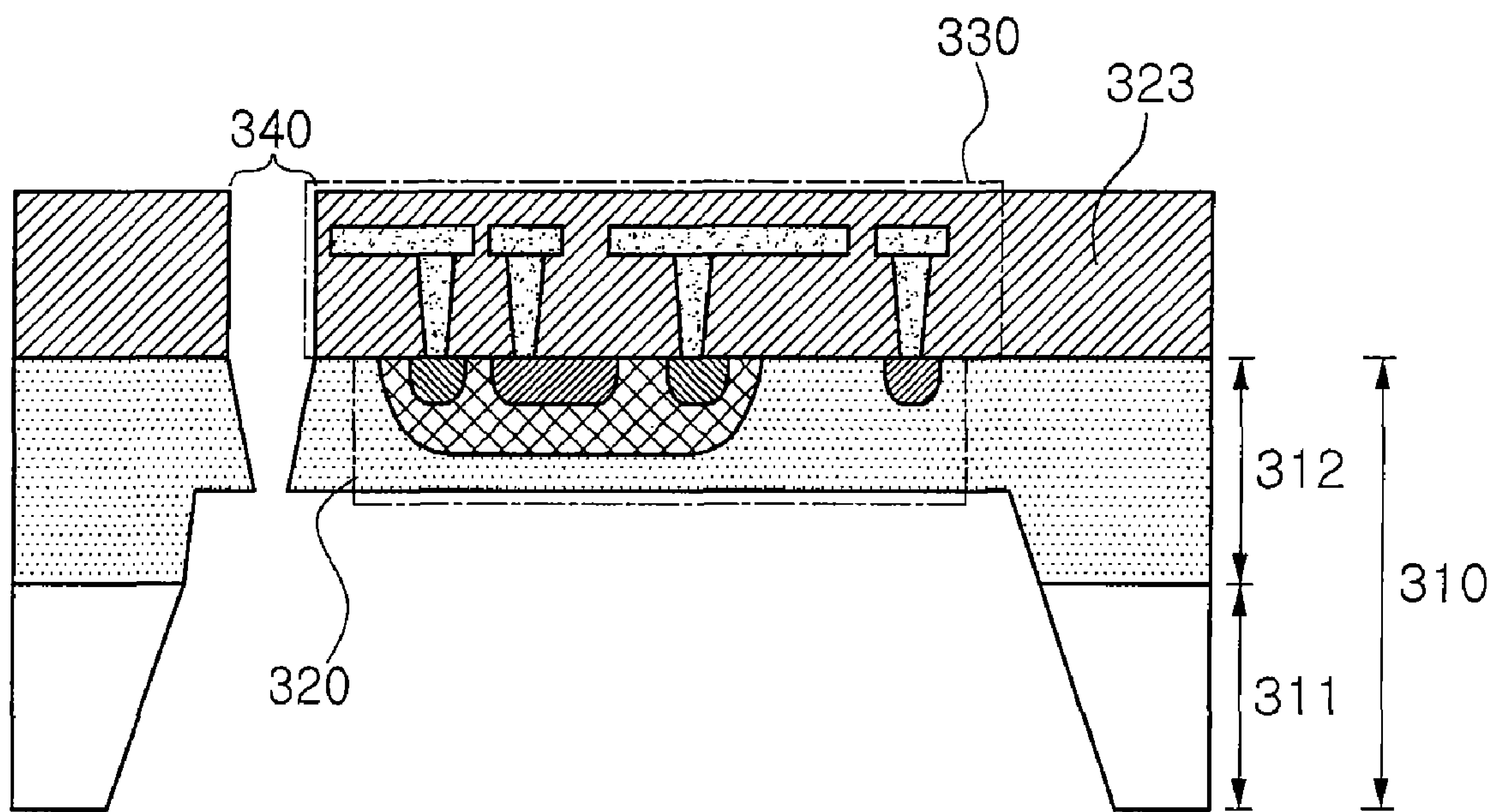


FIG. 5D

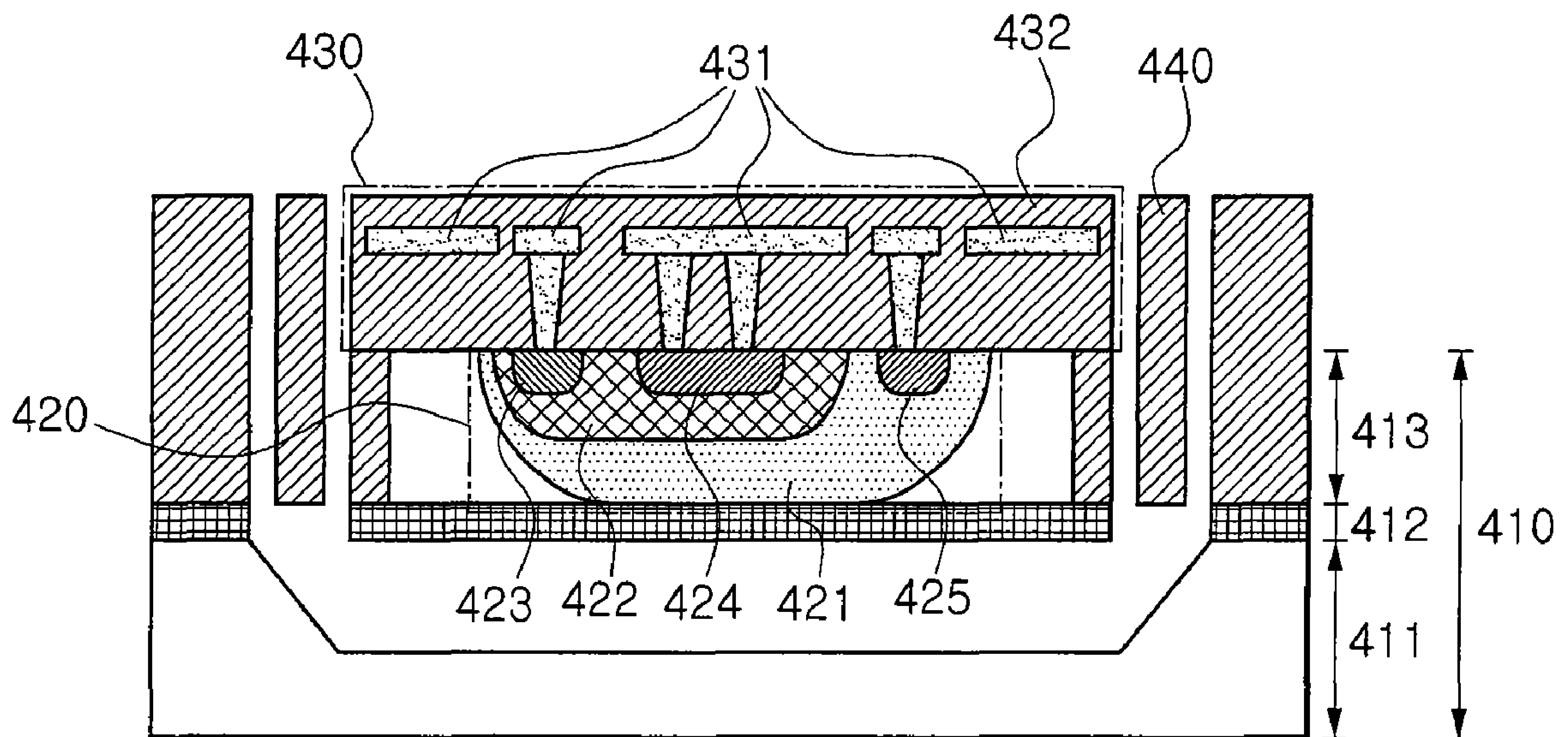


FIG. 6

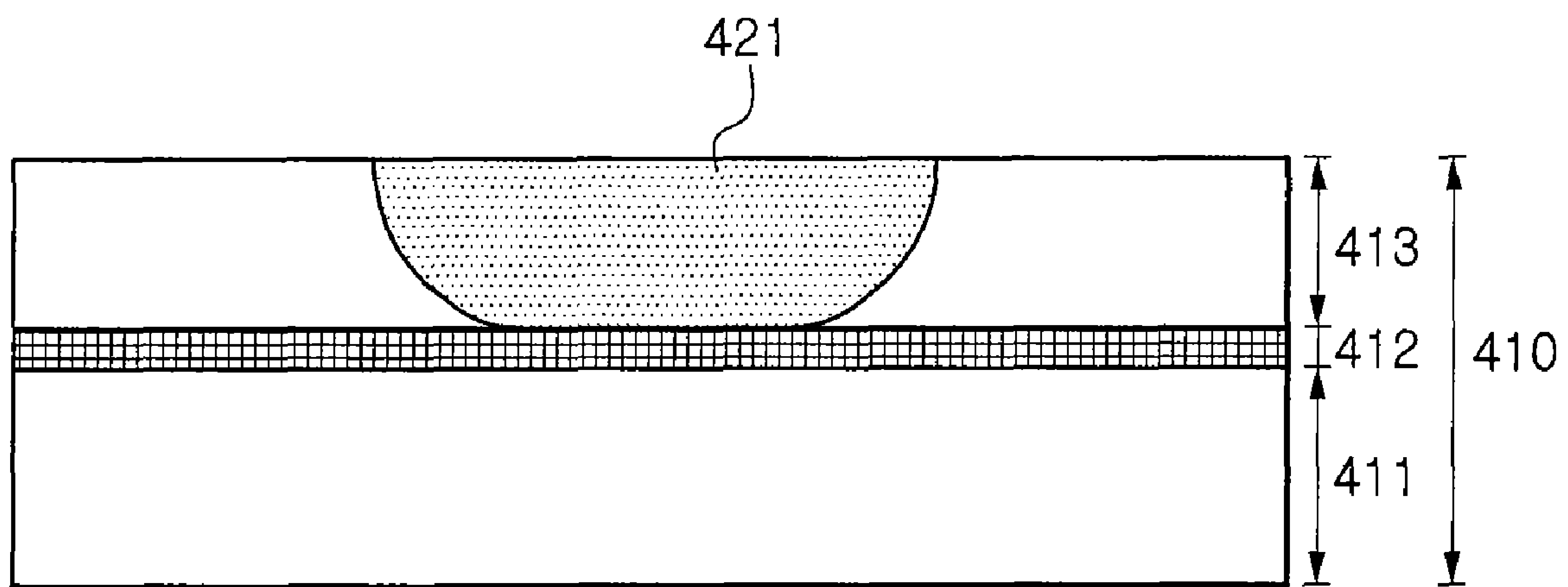


FIG. 7A

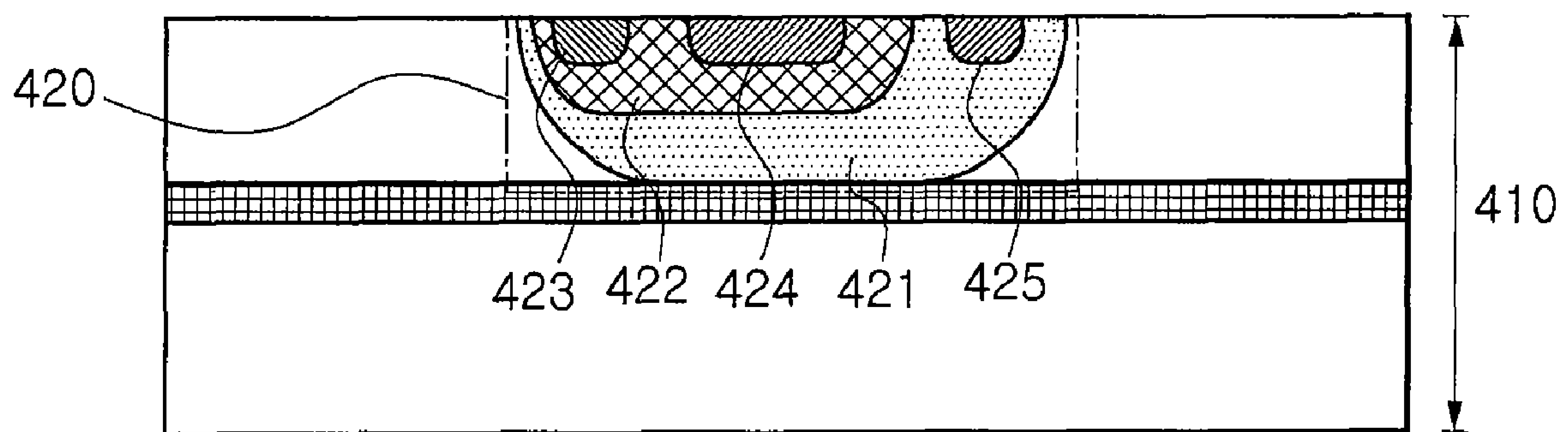


FIG. 7B

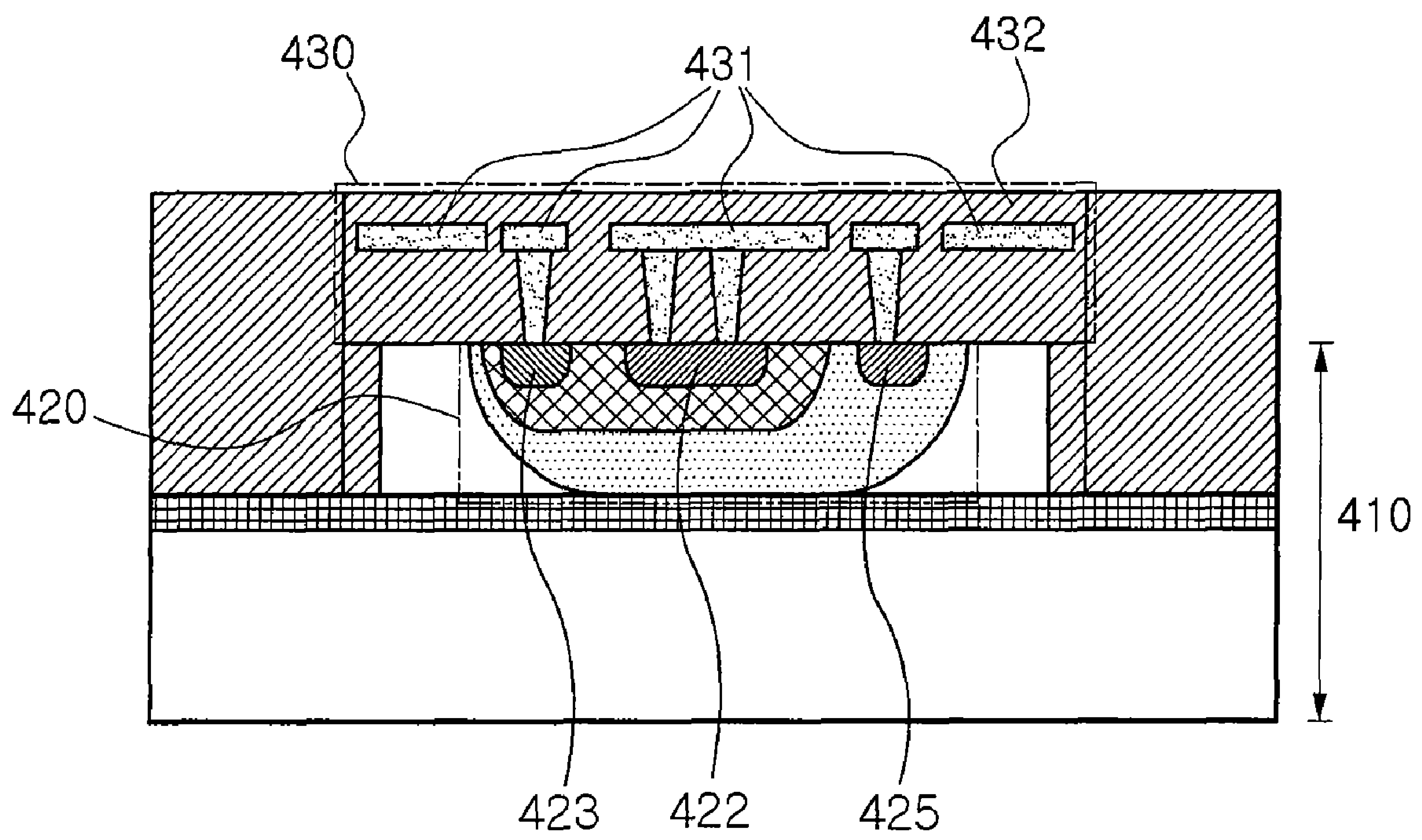


FIG. 7C

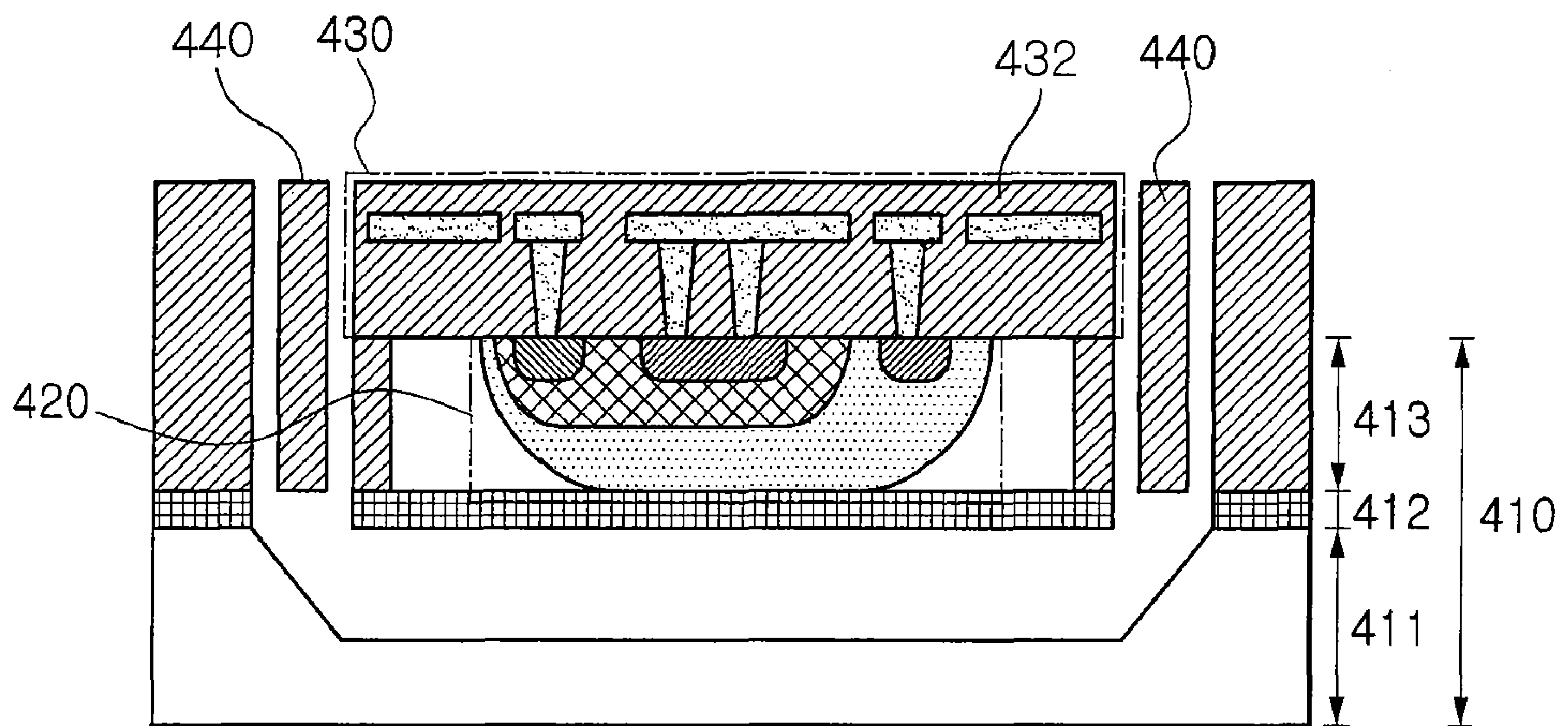


FIG. 7D

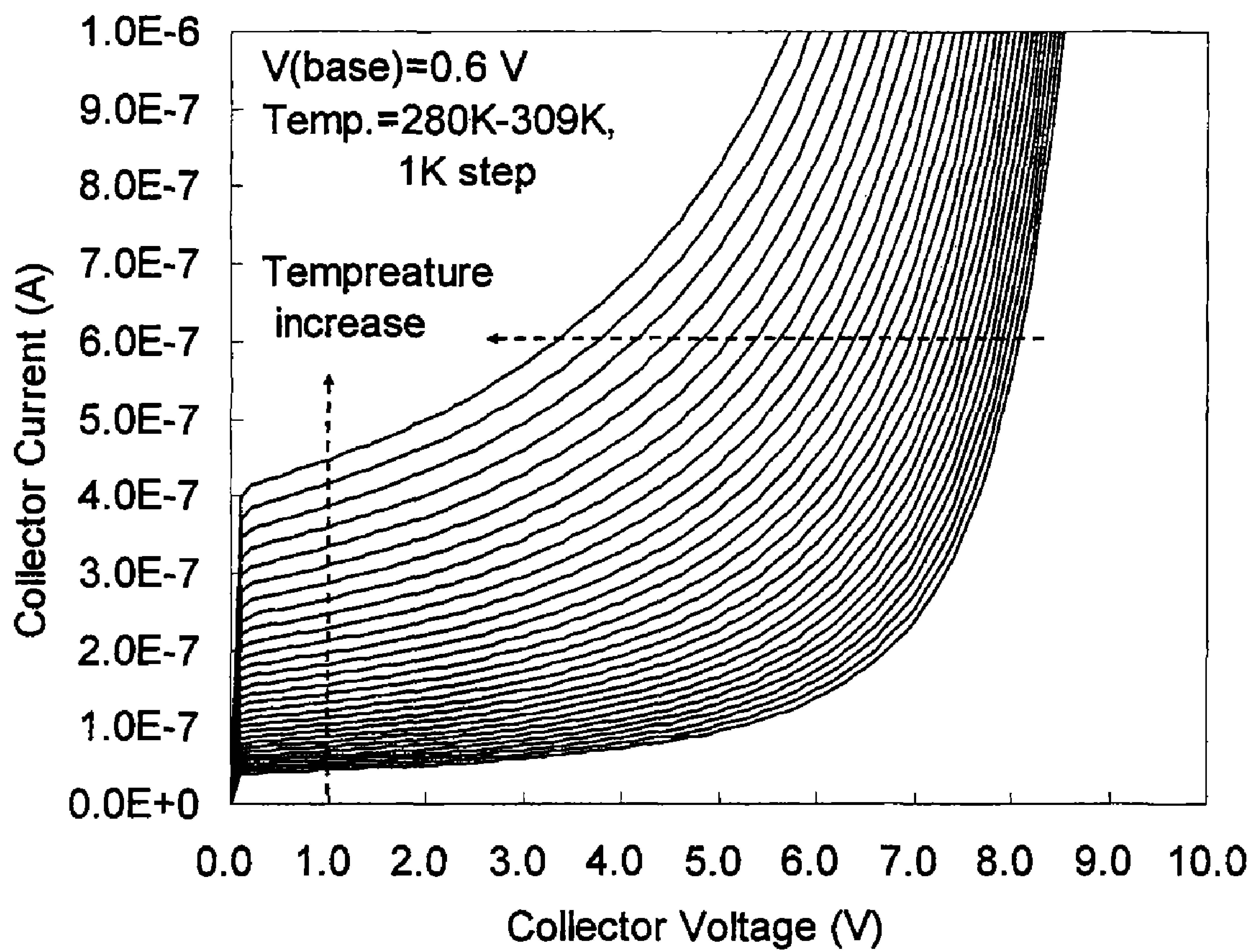


FIG. 8A

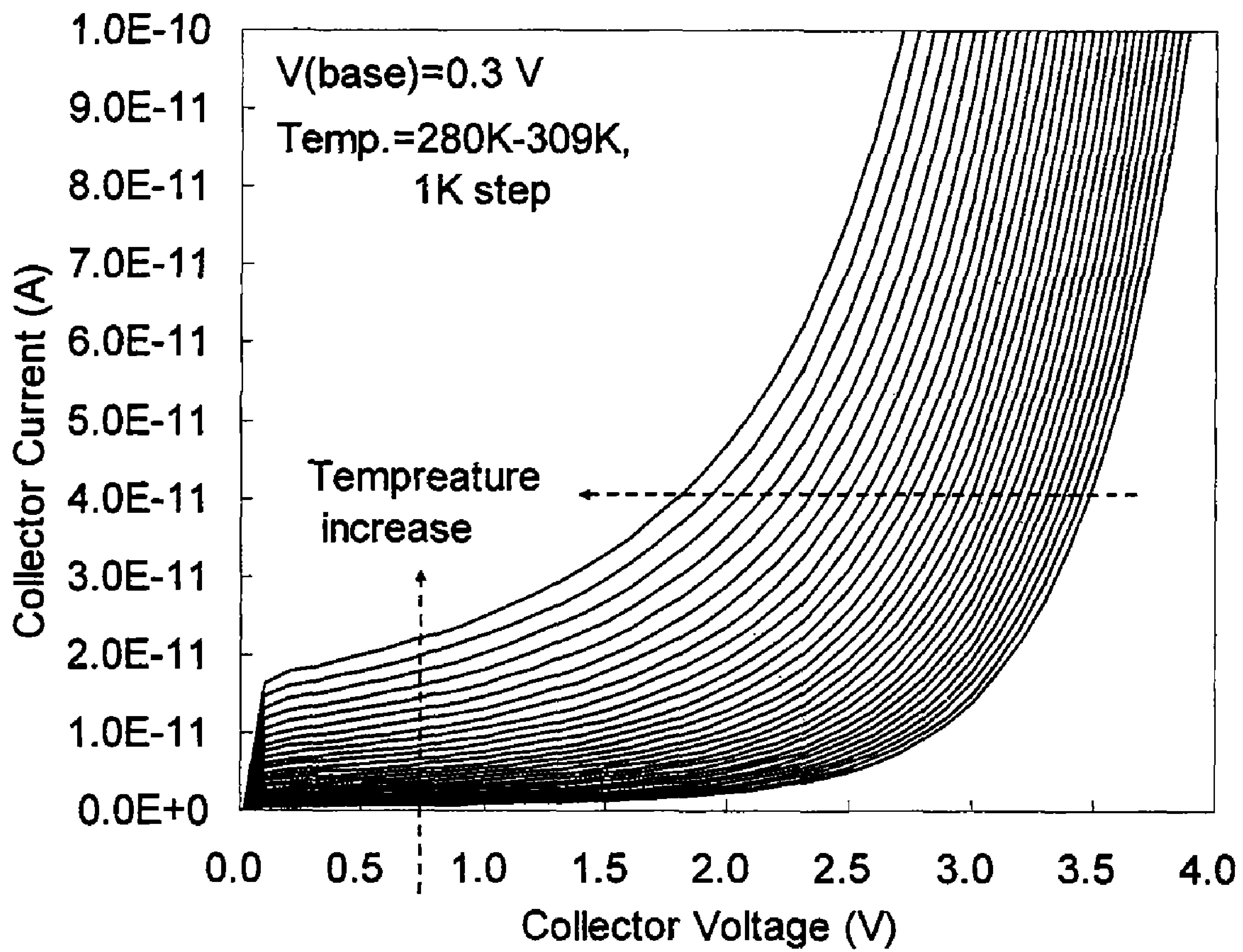


FIG. 8B

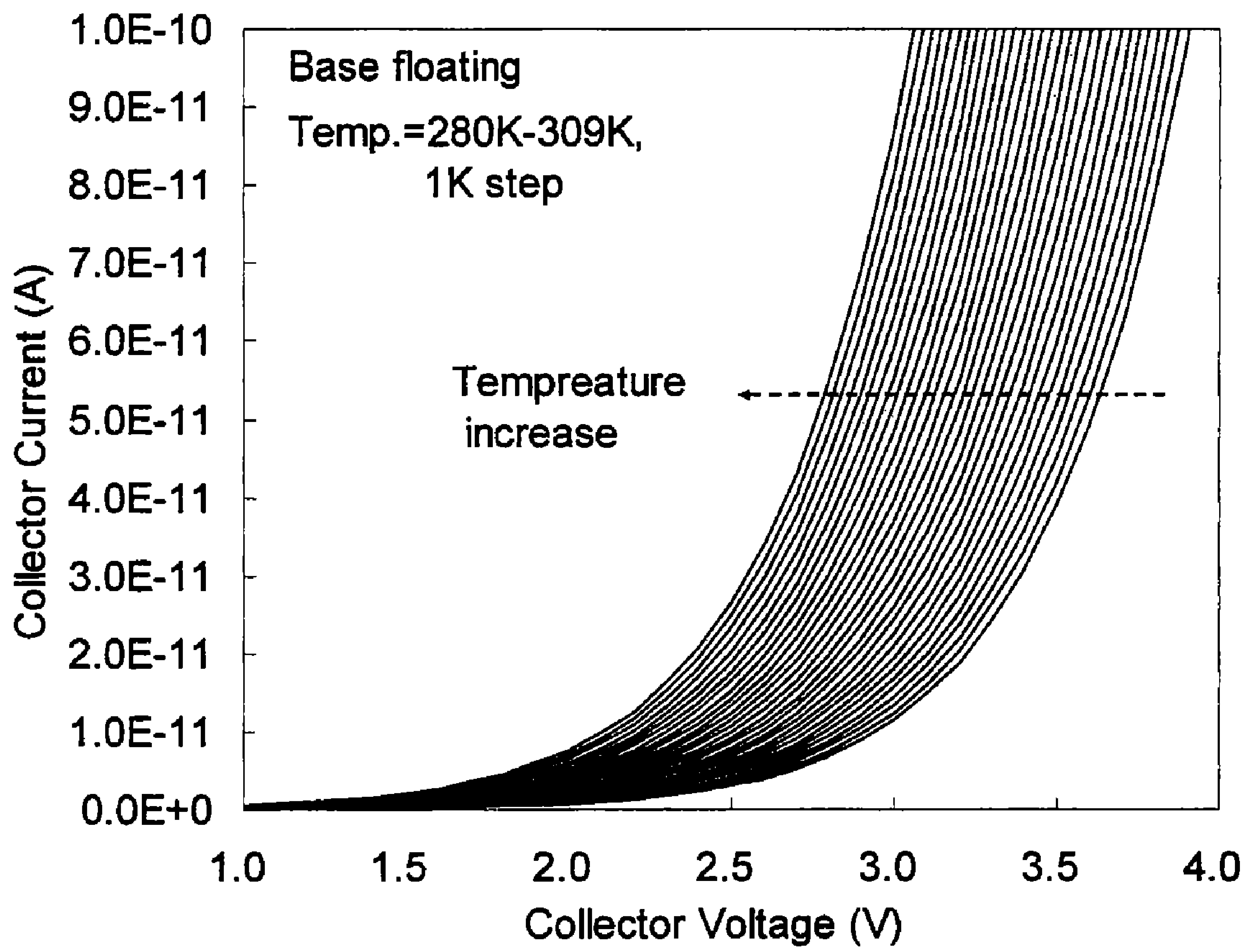


FIG. 8C

BIPOLAR JUNCTION TRANSISTOR-BASED UNCOOLED INFRARED SENSOR AND MANUFACTURING METHOD THEREOF

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the priority of Korean Patent Application No. 10-2007-110150 filed on Oct. 31, 2007, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an uncooled infrared (IR) imaging apparatus, and more particularly, to a bipolar junction transistor (BJT)-based uncooled IR sensor capable of being implemented through a complementary metal oxide semiconductor (CMOS) compatible process and improving temperature change detection characteristics.

2. Description of the Related Art

Recently, uncooled IR sensors has been actively researched and developed in terms of advantages such as a low production cost, a light weight, a low operating voltage, and a wide IR frequency band, etc. The applications of the uncooled IR sensors have been widened into a night IR imaging apparatus for a vehicle, an IR scope for a game machine, a security camera, thermal analysis, fire detection, and the like.

Particularly, in case of a CMOS process compatible IR sensor, since peripheral circuits such as a read-out integrated circuit (ROIC) can be formed on the same substrate for the IR sensor, a monolithic IR detection system can be implemented.

Therefore, a production cost can be greatly reduced, and operating characteristics such as noise reduction and an increase in signal processing speed can be improved.

On the other hand, various technologies for forming micro-bolometers on a substrate where the CMOS ICs are formed by using a surface micro-machining process to implement the uncooled IR sensor have been proposed.

In general, the micro-bolometers have a structure where the micro-bolometers are formed to be floated apart from the substrate in order to remove thermal noise caused from heat of the substrate. In addition, the micro-bolometers are constructed with heat absorption layers which absorb the heat and heat detection devices which detect a change in heat and change resistance thereof with a high temperature coefficient of resistance (TCR).

As an example of a heat detection device having a high TCR, there are VOx, polycrystalline SiGe, amorphous silicon, YBaCuO, and various metallic resistors, etc.

However, the VOx is not compatible with a CMOS process, but many additional processes as well as the CMOS process are needed. Accordingly, apparatuses for depositing the VOx and post-processing apparatus after the deposition of VOx are additionally needed, so that the production cost is increased.

In addition, due to an amorphous structure of the VOx, a low frequency noise is increased.

On the other hand, the polycrystalline SiGe or the amorphous silicon is compatible with the CMOS process. However, since a high-temperature heat treatment process for ensuring stability of resistor is additionally needed, the polycrystalline SiGe or the amorphous silicon cannot be integrated into a CMOS IC in a monolithic type. In addition, due to an amorphous characteristic, a low frequency noise is

increased. In addition, many additional processes such as thin film deposition, photolithography, and etching are needed.

In order to solve the aforementioned problems, a technology for implementing the heat detection device of the micro-bolometers by using PN diodes shown in FIG. **1** has been proposed.

According to some research, in temperature change detection characteristics of the uncooled IR sensor implemented by using the PN diode as the heat detection device, a rate of change in voltage according to a temperature is in a range of 1 to 3 mV/K. The value is much more excellent than the value of a silicon thermocouple, that is, in a range of 0.5 to 1 mV/K.

In addition, the PN diode sensor is compatible with a silicon CMOS process, and a minimum of additional process after the CMOS process is needed.

SUMMARY OF THE INVENTION

The resistor-based uncooled IR sensor such as VO_x and polycrystalline SiGe has temperature change detection characteristics of 20 to 30 mV/K (2 to 3%/K at an operating voltage of 1V). However, the PN diode-based uncooled IR sensor has a disadvantage in terms of the temperature change detection characteristics of 1 to 3 mV/K (0.1 to 0.3%/K at an operating voltage of 1V).

Therefore, similar to the PN diode-based uncooled IR sensor, an uncooled IR sensor capable of being implemented through a CMOS compatible process and obtaining excellent temperature change detection characteristics has been required.

According to an aspect of the present invention, there is provided a BJT (bipolar junction transistor)-based uncooled IR sensor comprising: a substrate; at least one BJT which is formed to be floated apart from the substrate; and a heat absorption layer which is formed on an upper surface of the at least one BJT, wherein the BJT changes an output value according heat absorbed through the heat absorption layer.

In the above aspect, in the at least one BJT, a base may be applied with a constant voltage (constant current), a collector may be applied with a constant voltage, and a current flowing through the collector may be changed according to heat absorbed through the heat absorption layer. In addition, in the at least one BJT, a base may be applied with a constant voltage, a collector may be applied with a constant current, and a voltage applied to the collector may be changed according to heat absorbed through the heat absorption layer.

According to another aspect of the present invention, there is provided a method of manufacturing a BJT (bipolar junction transistor)-based uncooled IR sensor, comprising: forming a BJT in a substrate; forming a heat absorption layer on an upper surface of the BJT; and etching the upper surface of the substrate contacting with a lower surface of the BJT so as for the BJT to be floated.

In the above aspect, the forming of the BJT may comprise: forming a well in the substrate; forming a base region in the well; forming a base and an emitter in the base region to be separated from each other; and forming a collector in the well where the base region is not formed.

In addition, the forming of the heat absorption layer may comprise: forming metal interconnection lines connected to the base, the emitter, and the collector; depositing an insulating layer on the upper surface of the substrate so as to cover the metal interconnection lines; and etching the insulating layer to form the heat absorption layer including the metal interconnection lines and the insulating layer.

In addition, the method may further comprise forming a support arm on the upper surface of the substrate so as to support the IR sensor.

According to still another aspect of the present invention, there is provided a method of manufacturing a BJT (bipolar junction transistor)-based uncooled IR sensor, comprising: etching a wafer including a substrate and an epitaxial layer to form a membrane structure; forming a BJT in the epitaxial layer; forming a heat absorption layer constructed with metal interconnection lines and an insulating layer by forming the metal interconnection lines on an upper surface of the BJT and depositing the insulating layer to cover the metal interconnection lines; and etching the insulating layer where the BJT and the heat absorption layer are not formed and the epitaxial layer to form a cantilever structure.

In the above aspect, the forming the BJT may comprise: forming a base region in the epitaxial layer; forming a first emitter, a base, and a second emitter in the base region to be separated from each other; and forming a collector in the epitaxial layer where the base region is not formed.

In addition, the forming of the heat absorption layer may comprise: forming the metal interconnection lines to be connected to the base, the first and second emitters, and the collector; and depositing the insulating layer on the upper surface of the wafer to cover the metal interconnection lines.

In addition, the etching of the insulating layer to form the cantilever structure may comprise: defining an opening region of the cantilever on a region of the insulating layer where the BJT and the heat absorption layer are not formed; etching the insulating layer through the opening region of the cantilever and etching the epitaxial layer by a thickness of the cantilever; and etching the epitaxial layer through a lower surface of the wafer to penetrate the insulating layer, the epitaxial layer, and the substrate.

According to a further still another aspect of the present invention, there is provided a method of manufacturing a BJT (bipolar junction transistor)-based uncooled IR sensor, comprising: forming a BJT in an SOI (silicon-on-insulator) wafer; forming a heat absorption layer on an upper surface of the BJT; and etching an upper surface of the SOI wafer contacting with a lower surface of the BJT so as for the BJT to be floated.

In the above aspect, the forming of the BJT may comprise: forming a well in the SOI wafer; forming a base region in the well; forming a base and an emitter in the base region to be separated from each other; and forming a collector in the well where the base region is not formed.

In addition, the forming of the heat absorption layer may comprise: forming metal interconnection lines to be connected to the base, the emitter, and the collector; depositing an insulating layer on an upper surface of the SOI wafer to cover the metal interconnection lines; forming a heat absorption layer constructed with the metal interconnection lines and the insulating layer by defining a heat absorption layer formation region and etching the insulating layer formed in the heat absorption layer formation region.

In addition, the method may further comprise forming a support arm on an upper surface of the substrate to support the IR sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the present invention will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

FIG. **1** is a cross-sectional view illustrating a conventional PN diode-based uncooled IR sensor;

FIG. **2** is a cross-sectional view illustrating a BJT-based uncooled IR sensor according to an embodiment of the present invention;

FIGS. **3**A to **3**D are cross-sectional views for explaining a method of manufacturing an uncooled IR sensor having the structure of FIG. **2**;

FIG. **4** is a cross-sectional view illustrating a BJT-based uncooled IR sensor according to another embodiment of the present invention;

FIGS. **5**A to **5**D are cross-sectional views for explaining a method of manufacturing an uncooled IR sensor having the structure of FIG. **4**;

FIG. **6** is a cross-sectional view illustrating a BJT-based uncooled IR sensor according to still another embodiment of the present invention;

FIGS. **7**A to **7**D are cross-sectional views for explaining a method of manufacturing an uncooled IR sensor having the structure of FIG. **6**; and

FIGS. **8**A to **8**C are graphs illustrating temperature change detection characteristics of an uncooled IR sensor according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Hereinafter, embodiments of the present invention will be described in detail with reference to the accompanying drawings. For clarifying the present invention, detailed description of well-known functions and constructions will be omitted.

In the accompanying drawing, elements having similar functions and operations are denoted by the same reference numerals.

FIG. **2** is a cross-sectional view illustrating a BJT-based uncooled IR sensor according to an embodiment of the present invention.

Referring to FIG. **2**, the uncooled IR sensor mainly includes a silicon substrate **210**, a bipolar junction transistor (BJT) **220** which is floated apart from the silicon substrate **210** and changes a voltage or current value according to heat absorbed through a heat absorption layer **230**, the heat absorption layer **230** which is disposed on an upper surface of the BJT **220** to absorb the heat, and a support arm **240** which fixes a position of the BJT **220**.

That is, in the uncooled IR sensor of FIG. **2**, a heat detection device is implemented with the BJT instead of a conventional PN diode.

The BJT **220** is applied with a constant voltage through a collector and with a constant voltage (constant current) through a base to change a collector current value according to a temperature of the heat absorption layer **230**. Otherwise, the BJT **200** is applied with a constant current through the collector and a constant voltage (constant current) through the base to change the collector voltage value according to the temperature of the heat absorption layer **230**.

The BJT **220** can detect a change in temperature of the heat absorption layer **230** by using an n-p-n or p-n-p junction characteristic, so that it is possible to obtain excellent temperature change detection characteristics. In addition, due to the BJT **220**, output signals can be stably detected in a wide range of operating voltage, and a silicon CMOS process compatible IR sensor can be manufactured.

As a result, the uncooled IR sensor of FIG. **2** can be integrated with a CMOS IC in a monolithic type and provide more excellent temperature change detection characteristics than a conventional uncooled IR sensor.

Now, a method of manufacturing the uncooled IR sensor having the structure of FIG. **2** will be described with reference to FIGS. **3**A to **3**D.

Firstly, as shown in FIG. **3**A, an n-type well **221** is formed in a predetermined region of a p-type silicon substrate **210**.

Next, as shown in FIG. **3**B, a p-type base region **222** is formed in the n-type well **221** through a p-type base ion implantation process and a diffusion process. Next, a p-type base **223** and an n-type emitter **224** are formed in the p-type base region **222** to be separated by a predetermined distance from each other through p+ active and n+ active ion implantation processes, respectively. Next, an n-type collector **225** is formed in the n-type well **221** where the p-type base region **222** is not formed.

As a result, the BJT **220** is formed to have an n+/p-type base/n-type well structure.

Subsequently, as shown in FIG. **3**C, metal interconnection lines **231** are formed to be connected to the p-type base **223**, the n-type emitter **224**, and the n-type collector **225** through a metal interconnection process. Polysilicons **241** used to form support arms **240** for supporting the to-be-floated IR sensor are formed on both sides of metal interconnection lines **231**. A passivation insulating layer **232** is deposited on the upper surface of the substrate **210** so as to cover the polysilicons **241** and the metal interconnection lines **231**.

The insulating layer **232** may be made of a silicon oxide film, a silicon nitride, a metal such as aluminum, and other materials such as bismuth.

Next, as shown in FIG. **3**D, opening regions are defined on the insulating layer **232** through a photolithography process, and dry etching is performed to form the heat absorption layer **230** constructed with the metal interconnection lines **231** and the insulating layer **232** and the support arms **240** constructed with the polysilicons **241** and the insulating layer **232**.

Next, an anisotropic wet etching process is electro-chemically performed on the upper surface of the substrate **210** contacting with lower surfaces of the BJT **220** and the support arm **240**, so that the BJT **220** is formed to be floated apart from the substrate **210**.

As a result, an IR sensor structure including the BJT **220** and the heat absorption layer **230** can be floated apart from the substrate **210**.

In the aforementioned embodiment, the support arm **240** is constructed in a combination of the polysilicon **241** and the insulating layer **232**. Alternatively, the support arm **240** may be constructed with only the insulating layer **232**.

FIG. **4** is a cross-sectional view illustrating a BJT-based uncooled IR sensor according to another embodiment of the present invention.

Similarly to the uncooled IR sensor of FIG. **2**, the uncooled IR sensor of FIG. **4** includes a substrate **311**, an epitaxial layer **312**, a BJT **320** formed in the epitaxial layer **312**, and a heat absorption layer **330** formed on an upper surface of the BJT **320**. Particularly, in the embodiment, the BJT **320** is formed on a cantilever structure of the epitaxial layer **312** so that the BJT **320** can be thermally isolated from the substrate **311**.

That is, the uncooled IR sensor of FIG. **4** is implemented by using a wafer **310** where the n-type epitaxial layer **312** is formed on the p-type silicon substrate **311**.

Now, a method of manufacturing the uncooled IR sensor having the structure of FIG. **4** will be described with reference to FIGS. **5**A to **5**D.

Firstly, as shown in FIG. **5**A, an anisotropic etching process using chemicals such as KOH is performed on a lower surface of the silicon substrate **311** so as to form a membrane structure.

Next, as shown in FIG. **5**B, a p-type base region **321** is formed in the n-type epitaxial layer **312** through a p-type base ion implantation process and a diffusion process. Next, an n-type emitter **322**, a p-type base **323**, and an n-type emitter **324** are formed in the p-type base region **321** through n+ active and p+ active ion implantation processes. Next, an n-type collector **325** is formed in the n-type epitaxial layer **312** where the p-type base region **321** is not formed.

As a result, the BJT **320** is formed to have an n+/p-type base/n-type epitaxial layer structure.

Next, as shown in FIG. **5**C, metal interconnection lines **331** are formed to be connected to the p-type base **323**, the n-type emitters **322** and **324**, and the n-type collector **325** through a metal interconnection process. A passivation insulating layer **332** is deposited on the upper surface of the n-type epitaxial layer **312** so as to cover the metal interconnection lines **331**.

Next, as shown in FIG. **5**D, in order to a cantilever structure from the membrane structure, a cantilever opening region **340** is defined, and the insulating layer **332** deposited on a portion corresponding to the opening region **340** is etched. Subsequently, the epitaxial layer **312** is etched by a thickness of the cantilever.

Next, a lower surface of the epitaxial layer **312** is etched to penetrate the cantilever opening region **340**. As a result, an IR sensor including the BJT **320** and the heat absorption layer **330** is formed to have the cantilever structure, so that the IR sensor can be thermally isolated from the substrate **311**.

FIG. **6** is a cross-sectional view illustrating a BJT-based uncooled IR sensor according to still another embodiment of the present invention.

Similar to the uncooled IR sensor of FIG. **2**, the uncooled IR sensor of FIG. **6** includes a substrate **410**, a BJT **420**, a heat absorption layer **430**, and a support arm **440**. In here, the substrate **410** is constructed with a silicon-on-insulator (SOI) wafer.

Now, a method of manufacturing the uncooled IR sensor having the structure of FIG. **6** will be described with reference to FIGS. **7**A to **7**D.

For the convenience of description, in FIGS. **7**A to **7**D, an SOI wafer **410** manufactured by sequentially laminating a silicon substrate **411**, a buried oxide (BOX) **412**, and a p-type silicon **413** is exemplified.

Firstly, as shown in FIG. **7**A, an n-type well **421** used to form a collector of the BJT **420** is formed in the p-type silicon **413** of the SOI wafer **410** through a general CMOS process.

Next, as shown in FIG. **7**B, a p-type base region **422** is formed in the n-type well **421** through a p-type base ion implantation process and a diffusion process. Next, a p-type base **423** and an n-type emitter **424** are formed in the p-type base region **422** through n+ active and p+ active ion implantation processes. Next, an n-type collector **425** is formed in the n-type well **421** where the p-type base region **422** is not formed.

As a result, the BJT **420** is formed to have an n+/p-type base/n-type well structure.

Next, as shown in FIG. **7**C, metal interconnection lines **431** are formed to be connected to the p-type base **423**, the n-type emitter **424**, and the n-type collector **425** through a metal interconnection process. A passivation insulating layer **432** is deposited on the upper surface of the SOI wafer **410** so as to cover the metal interconnection lines **431**.

Next, as shown in FIG. **7**D, an opening region of an insulating layer **432** is defined through a photolithography process, and the insulating layer **432** deposited on a portion corresponding to the opening region **340** is dry-etched. As a result, the heat absorption layer **430** constructed with the

metal interconnection line **431** and the insulating layer **432** and the support arm **440** constructed with the insulating layer **432** are implemented.

Next, a wet etching process is performed on the silicon substrate **411** disposed on a lower surface of the BJT **420**, so that the IR sensor structure constructed with the BJT **420** and the heat absorption layer **430** is formed to be floated apart from the silicon substrate **411**.

In the aforementioned embodiment, the support arm **440** is constructed with only the insulating layer. Alternatively, the support arm **440** may be constructed in a combination of a polysilicon and the insulating layer similar to FIG. **2**.

FIGS. **8**A to **8**C are graphs illustrating temperature change detection characteristics of an uncooled IR sensor according to the present invention. FIG. **8**A illustrates a case where a base of a BJT is applied with a constant voltage of 0.6V and a collector voltage is changed. FIG. **8**B illustrates a case where the base of the BJT is applied with a constant voltage of 0.3V and the collector voltage is changed. FIG. **8**B illustrates a case where the base of the BJT is in a floating state and the collector voltage is changed.

The uncooled IR sensor having the structure of FIG. **2** is used. Areas of the emitter, base, and collector are designed to be 6, 7, and 8 μm^{2}', respectively.

Referring to FIG. **8**A, when the collector is applied with a constant voltage of 1V, a rate of change in collector current according to a temperature is about 8%/K. When the collector is applied with a constant current of 6×10^{-7} A, a rate of change in collector voltage according to a temperature is very high value such as 150 mV/K (average). In addition, it can be seen that a rate of change in the collector voltage is proportional to the temperature.

Referring to FIG. **8**B, when the collector is applied with a constant voltage of 0.75V, a rate of change in collector current according to a temperature is about 12%/K. When the collector is applied with a constant current of 4×10^{-11} A, a rate of change in collector voltage according to a temperature is very high value such as 60 mV/K (average).

Referring to FIG. **8**C, when the collector is applied with a constant voltage of 0.5V, a rate of change in collector current according to a temperature is about 10%/K. When the collector is applied with a constant current of 5×10^{-7} A, a rate of change in collector voltage according to a temperature is very high value such as 33 mV/K. In addition, it can be seen that a rate of change in the collector voltage according to a temperature is constant.

In the BJT-based uncooled IR sensor according to the present invention, a rate of change in current according to a temperature is in a range of 8 to 12%/K, and a rate of change in voltage according to a temperature is in a range of 33 to 150 mV/K. Therefore, it can be seen that the BJT-based uncooled IR sensor has more excellent temperature change detection characteristics than conventional PN diode-based uncooled IR sensors or resistor-based uncooled IR sensors using such as a resistor VO_x.

According to a BJT-based uncooled IR sensor and a manufacturing method therefor according to the present invention, a heat detection device is implemented with a BJT instead of a PN diode, so that it is possible to obtain more excellent temperature change detection characteristics and to stably detect output signals in a wide range of operating voltage. In addition, it is possible for the BJT-based uncooled IR sensor to be compatible with a silicon CMOS process.

While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.

What is claimed is:

1. A bipolar junction transistor (BJT)-based uncooled IR sensor comprising:
- a substrate;
- at least one BJT which is formed to be floated apart from the substrate; and
- a heat absorption layer which is formed on an upper surface of the at least one BJT,
- wherein the BJT changes an output value according heat absorbed through the heat absorption layer, and
- wherein in the BJT, a base is applied with a constant voltage, a collector is applied with a constant voltage, and a current flowing through the collector is changed according to heat absorbed through the heat absorption layer.

2. A bipolar junction transistor (BJT)-based uncooled IR sensor comprising:
- a substrate;
- at least one BJT which is formed to be floated apart from the substrate; and
- a heat absorption layer which is formed on an upper surface of the at least one BJT,
- wherein the BJT changes an output value according heat absorbed through the heat absorption layer, and
- wherein in the BJT, a base is applied with a constant voltage, a collector is applied with a constant current, and a voltage applied to the collector is changed according to heat absorbed through the heat absorption layer.

3. A bipolar junction transistor (BJT)-based uncooled IR sensor comprising:
- a substrate;
- at least one BJT which is formed to be floated apart from the substrate; and
- a heat absorption layer which is formed on an upper surface of the at least one BJT,
- wherein the BJT changes an output value according heat absorbed through the heat absorption layer, and
- wherein in the BJT, a base is applied with a constant current, a collector is applied with a constant voltage, and a current flowing through the collector is changed according to heat absorbed through the heat absorption layer.

4. A bipolar junction transistor (BJT)-based uncooled IR sensor, comprising:
- a substrate;
- at least one BJT which is formed to be floated apart from the substrate; and
- a heat absorption layer which is formed on an upper surface of the at least one BJT,
- wherein the BJT changes an output value according heat absorbed through the heat absorption layer, and
- wherein in the BJT, a base is applied with a constant current, a collector is applied with a constant current and a voltage applied to the collector is changed according to heat absorbed through the heat absorption layer.

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